Journal of Climate Change Research 2016, Vol. 7, No. 3, pp. 217～229
DOI: http://dx.doi.org/10.15531/KSCCR.2016.7.3.217

Environmental Assessment of Smart Grid Station Project Centered on Pilot Project of Korea Electric Power Corporation Building

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ABSTRACT

Increased evidences reveal that the global climate change adversely affect on the environment. Smart grid system is one of the ways to reduce greenhouse gas emissions in the electricity generation sector. Since 2013, Korea Electric Power Corporation (KEPCO) has installed smart grid station in KEPCO office buildings. The goal of this paper is two folds. One is to quantify the reduction in greenhouse gas emissions through smart grid stations installed in KEPCO office buildings as a part of pilot project. Among components of smart grid stations, this research focused on the photovoltaic power system (PV) and energy storage system (ESS). The other is to estimate the reduction in greenhouse gas emissions when PV is applied on individual houses. Results show that greenhouse gas emissions reduce 5.8～11.3% of the emissions generated through the electricity usage after PV is applied in KEPCO office buildings. The greenhouse gas emissions reduction from ESS is not apparent. When PV of 200～500 W is installed in individual houses, annual greenhouse gas emission reduction in 2016 is expected to be approximately 2.2～5.4 million tCO_2-eq, equivalent to 6～15% of greenhouse gas emissions through the electricity usage in the house hold sector. The saving of annual electricity cost in the individual house through PV of 200 W and 500 W is expected to be 47～179 thous and KRW and 123～451 thousand KRW, respectively. Results analyzed in this study show the environmental effect of the smart grid station. In addition, the results can be further used as guidance in implementing similar projects.

Key words: *Climate Change, Greenhouse Gas Emissions, Korea Electric Power Corporation (KEPCO), Photovoltaic Power System (PV), Energy Storage System (ESS)*

1. BACKGROUND

With higher awareness of the impacts of climate changes on sustainable growth of humanity, climate change has become one of the biggest global interests (Baek and Park, 2015). The increase of greenhouse gas concentration in the atmosphere due to reckless consumption of fossil fuels since industrialization is one of the most important factors in climate changes caused by the human being. The carbon dioxide concentration was remained below 280 ppm prior to industrialization, but it exceeded 400 ppm in Mauna Loa, Hawaii, in May 2014 (Yue *et al.*, 2015). The dramatic increase of carbon dioxide concentration is one of the major sources of a threat to the sustainable growth of humanity caused by unusual weather conditions such as rise in average global temperature, which in turn is leading to rise in sea levels, regional drought, heavy rains and snowfalls, etc (Baek and Park, 2015; Park and Russell, 2013). To minimize such problems, the international community is making great efforts to control the increment of average temperature at 2℃ to a level prior to industrialization (EG_Science, 2008; Pachauri and Reisinger, 2007). In order to suppress the average temperature rise within 2℃, the level of carbon dioxide concentration in the atmosphere must be maintained within 450 ppm. However, as the ambient carbon dioxide concentration already exceeded 400 ppm, finding ways to control greenhouse gas emissions are very urgent (IEA, 2015).

In order to actively respond to climate changes, the international community has agreed to launching “Durban Platform”

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Received August 12, 2016 / Revised August 29, 2016 / Accepted September 9, 2016

at the COP17 (Durban, South Africa) in 2011. "Durban Platform" can be said to be a preparation stage for establishing a new climate system that all the countries should be directly involved in after 2020. At the COP19 (Warsaw, Poland) in 2013, the "Nationally Determined Contributions (NDCs)" to control the global average temperature within 2℃ compared to the level prior to industrialization was autonomously decided and was determined to be submitted at the COP21 (Paris, France) in 2015. Korea has submitted the NDC for 37% reduction compared to 2030 Business As Usual (BAU) greenhouse gas emissionin June 2015.

The amount of carbon dioxide emissions accounts for 91.5 % of all greenhouse gas emissions in Korea based on 2013. In addition, 93.8% of carbon dioxide emissions are produced by the energy sector (GIR, 2015). Such high levels of carbon dioxide emissions in the energy sector imply that Korea is still heavily dependent on fossil energy. In addition, Korea imports most of such fossil energy sources. For instance, 95.7% of the primary energy sources were imported in 2013. Since majority of fossil energy sources imported are limited to few countries, energy security is currently vulnerable in Korea. For example, 86% of total oil imports, which accounts for approximately 38 % of total energy consumption based on 2013, was imported from countries in the Middle East (KEMCO, 2014). The cost of energy imports accounts for 34.7% of all import costs of the country based on 2013, which is equivalent to $178.7 billion. This figure is higher than the total export amount in 2013 from Korea's main exports (ships, semiconductors, and automobiles) that amount to $142.9 billion. Therefore, reinforcement of energy security and searching for ways to reduce greenhouse gases for sustainable growth are needed in Korea.

As a part of the efforts toward sustainable growth through energy saving and reduction of greenhouse gas emissions, the Korea Electric Power Corporation is promoting the Smart Grid Station Construction Project (Kim, *et al.*, 2015). A smart grid station refers to a control center that efficiently operates building's use of electricity by integrating information and communications technology. The smart grid station includes components such as PhotoVoltaic power system (PV), (Power Conversion System (PCS), Energy Storage System (ESS), smart devices (outlet, lighting, panel board), Building Automation System (BAS), and Automatic Metering Infrastructure (AMI) (Lee, *et al.*, 2014; Rue, 2014).

The Korea Electric Power Corporation began a pilot smart grid station construction project in 2013 starting with the Namyangju Branch Office building in Guri-si, Gyeonggi-do. In 2014, a total of 29 office building smart grid stations were built at above 300 kW contract power. Based on the economic and environmental evaluation result of smart grid stations built in office buildings, the Korea Electric Power Corporation plans to fully promote the expansion of smart grid station project in the future. The purpose of this study is to provide a base data for determining the direction of future smart grid station projects through environmental assessment of smart grid stations.

2. EMISSION FACTOR ESTIMATION

The environmental aspect of photovoltaic power system and energy storage system were especially assessed among the components of smart grid stations. The environmental aspect was calculated based on the level of greenhouse gas emission reduction following construction of smart grid stations.

2.1 Annual Average Emission Factor

The emission factor from power production per fuel was calculated through the weighted-average based on the power generation quantity. Carbon dioxide had the highest proportion in volume among the greenhouse gases emitted from power production. In addition, small amounts of methane and nitrous oxide were emitted. Here, each of the methane and nitrous oxide's global warming potential of 21 and 310 were applied to convert the unit of greenhouse gas emission factor to CO_2-eq. The greenhouse gas emission factor used in this study is IPCC Tier 1 emission factor (IPCC, 2006). As a result of using the electric power production ratio per annual generating unit in 2014 in this study, the emission factor was found to be 0.000465 tCO_2-eq/kWh (Table 1) (KPX, 2015).

2.2 Hourly Emission Factor

Because the contribution of energy sources to electricity generation changes with time, there are differences in emission factors according to time as well (Fig. 1). When the variation of generation quantity is observed hourly, the generation quan-

Table 1. Annual electricity generation of each source of energy in 2014 (KPX, 2015)

	Nuclear	Coal	LNG	Oil	New & renewable	Total
Electricity production (GWh)	149,199	197,223	116,285	7,596	21,533	491,836
Ratio (%)	30	40	24	2	4	100

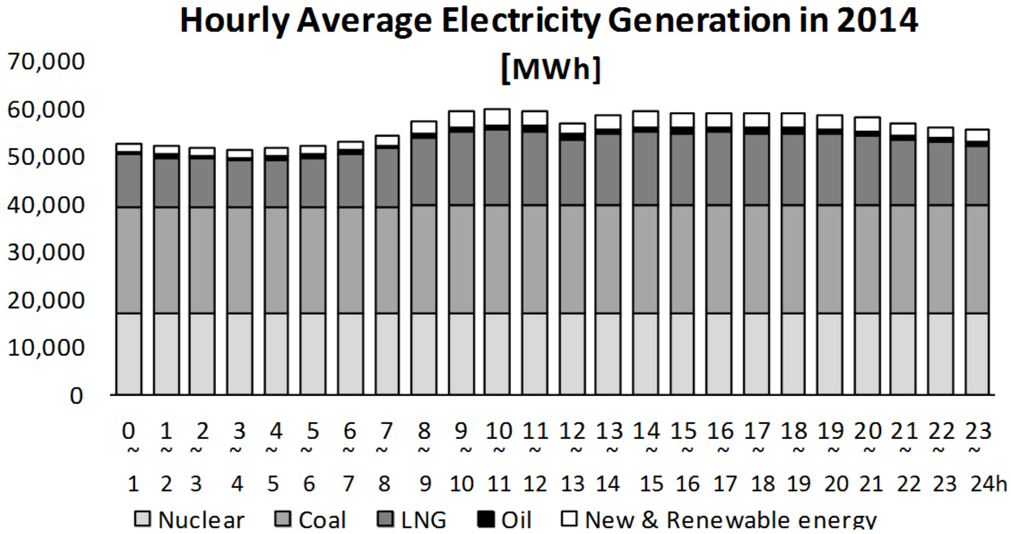

Fig. 1. Hourly average electricity generation of each source of energy in 2014 (KPX, 2015).

tity was found to be relatively high from 8 am to 9 pm. In addition, the reduction of generation quantity during the lunch hour from 12 pm to 1pm was clearly shown. In terms of hourly generation quantity per fuel, there weren't any significant variations in the case of nuclear power generation and coal-fired power generation. The fuel with the highest hourly variation was LNG. Although the hourly variation of renewable energies are clearly visible, it was not significant in terms of entire generation quantity because the generation quantity of renewable energies were small compared to other energy sources.

The hourly power generation ratio per fuel source clearly showed the hourly variation of LNG (Fig. 2). Due to such variations, the emission factor according to power generation also showed differences per hour (Fig. 3). It showed the emission factor was the highest during 12 pm and 1pm when the LNG generation ratio, which has low greenhouse gas emission quantity compared to coal-fired power generation, was relatively low. In addition, emission factor was found to be the lowest during 11 am to 12 pm when the LNG generation ratio is the highest.

3. ENVIRONMENTAL ASSESSMENT OF KOREA ELECTRIC POWER CORPORATION OFFICE BUILDING SMART GRID STATION PILOT PROJECT

3.1 Smart Grid Construction Status

Smart grid stations were constructed through four different types (over 1,000 kW, 700~1,000 kW, 500~700 kW, and 300~500 kW) according to the contract power of Korea Electric Power Corporation office buildings (Table 2). The number of office buildings implemented with smart grid station per contract power in 2014 corresponds to nine for above 1,000 kW, four for 700~1,000 kW, five for 500~700 kW, and 11 for 300~500 kW. Photovoltaic power system (PV) and energy storage system (ESS) capacities were separately set according to contract power. Greenhouse gas emission quantity caused

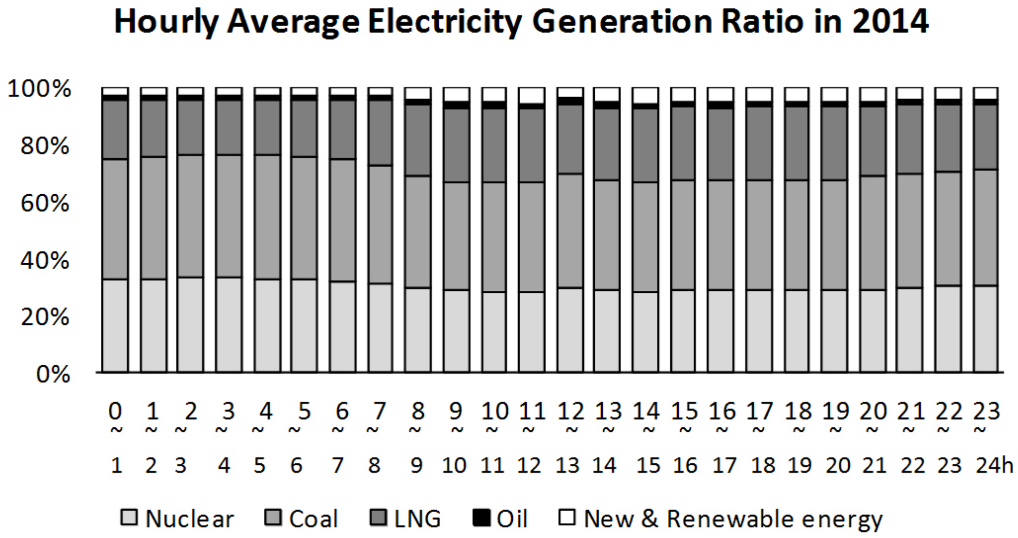

Fig. 2. Hourly average electricity generation ratio of each source of energy in 2014 (KPX, 2015).

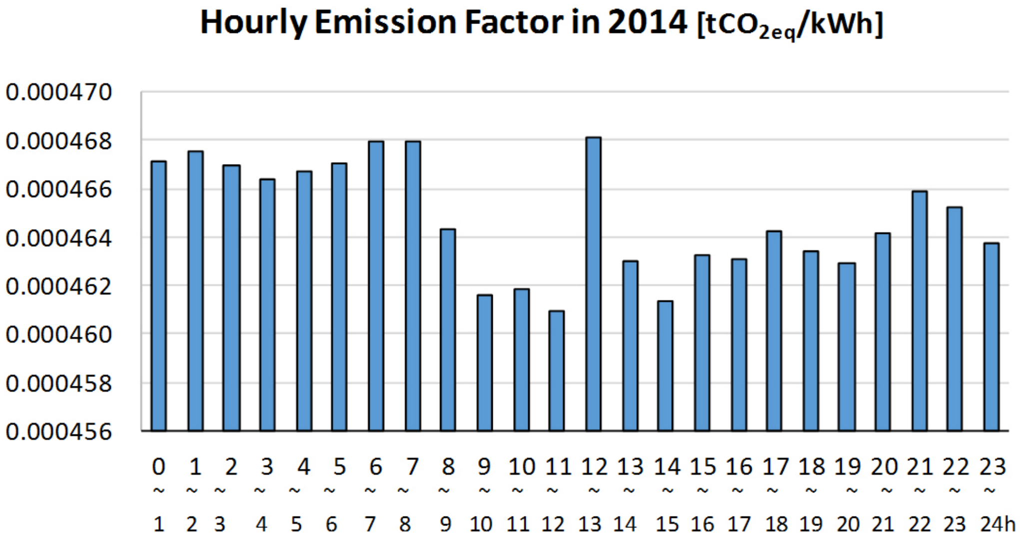

Fig. 3. Hourly emission factors of each kWh of electricity generation in 2014 (KPX, 2015).

by power generation per office building was calculated based on the annual average power consumption standard (Table 2).

3.2 Greenhouse Gas Reduction by Photovoltaic Power System

Reduction of greenhouse gas emission through implementation of PV was calculated based on generation quantity of PV. Here, the greenhouse gas emission during power generation by PV was assumed to be zero. The generation quantity of PV was calculated by multiplying the PV capacity and annual hours of sunshine. Therefore, the most important factor in determining the power production quantity of PV is the hours of sunshine.

The annual average hours of sunshine during the 20 years from 1988 to 2007 was 1,885~2,123 hours depending on the region (KMA, 2008). When this is converted to daily average value, it is approximately 5.2~6.3 hours. In addition to hours of sunshine, PV efficiency is also another important factor that determines power production quantity (Lee, 2011). The efficiency of PV is known to be approximately 0.64~0.72 due to

Table 2. Annual greenhouse gas emissions due to electricity generation

Contract demand		Over 1,000 kW	700~1,000 kW	500~700 kW	300~500 kW
(A) Number of office buildings in which smart grid stationis installed in 2014		9	4	5	11
(B) Annual average electric usage of each building [Unit: kWh]		1,704,204	1,206,441	489,307	261,459
(C) Greenhouse gas emission reduction due to electricity generation (B× 0.000465) [Unit: tCO_2-eq]		792.5	561.0	227.5	121.6
PV	Capacity [kW]	100	40	30	20
	Cost [million KRW]	207.0	89.8	67.0	51.0
ESS	Capacity [kWh]	200	100	80	50
	Cost [million KRW]	120.0	60.0	48.0	30.0

changes in the direction and altitude of incident light, concentration of fine dusts in the atmosphere and clouds, and changes in weather conditions such as temperature. Therefore, with the application of such efficiency factors to hours of sunshine, the possible hours of sunshine is 3.3~4.5 hours. In this study, the power generation time of PV was assumed to be on average 3.5 hours per day.

From the result of applying the emission factor of 0.000465 tCO_2-eq/kWh calculated by using electric power production ratio per generating unit in 2014, the annual greenhouse gas reduction rate per size of Korea Electric Power Corporation office buildings in 2014 were 59 tCO_2-eq (over 1,000 kW), 24 tCO_2-eq (700~1,000 kW), 18 tCO_2-eq (500~700 kW), and 12 tCO_2-eq (300~500 kW), respectively (Table 3). This corresponds to 7.5% (over 1,000 kW), 4.2% (700~1,000 kW), 7.8% (500~700 kW), and 9.8% (300~500 kW) of greenhouse gas emission quantity from power generation per office building (Fig. 4).

Economic aspect of PV implementation can be evaluated from multiple perspectives. For example, the reduction in electricity bill for consumers from installation of PV can be converted to economy. Also, reduction of purchasing electricity from reduction in electricity usage can be converted to economy. As such, economic aspect can be assessed in various

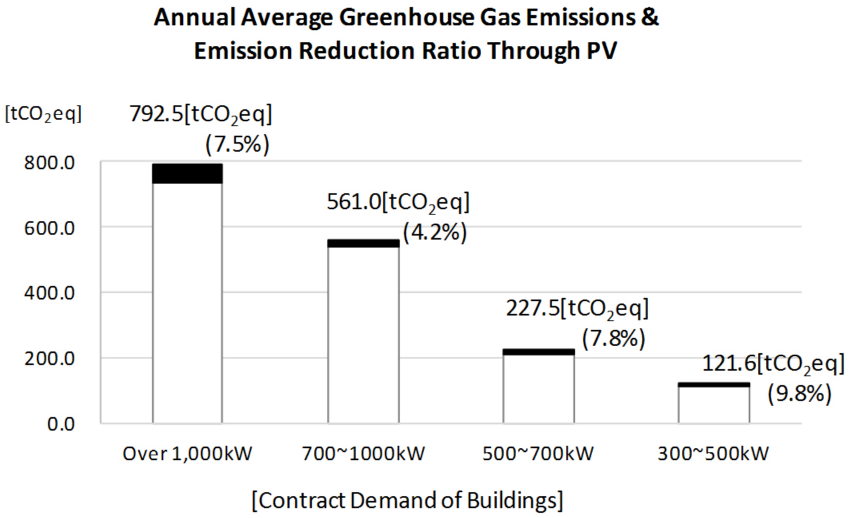

Fig. 4. Annual average greenhouse gas emissions of each building [tCO_2-eq] and greenhouse gas emission reduction ratio [%] due to PV installation (illustrated inside the parenthesis on the figure).

ways. In order to convert greenhouse gas reduction amount into economy in this study, the greenhouse gas emission trading price of Korea Exchange that has been implemented since 2015 was used. The emission trading price based on Oct. 8, 2015 was 12,050 KRW (Chae and Park, 2016; Lee, 2011). In this study, one ton of greenhouse gas was converted to 12,000 KRW. The estimated greenhouse gas reduction and PV installation cost were compared (Table 3).

As a result, greenhouse gas reduction effect per 1 million KRW PV installation cost was found to be approximately 3.36 thousand KRW (Fig. 5). This result shows the economy in comparison to the cost in the year of PV installation. Of course, the economy compared to cost increases depending on the duration when considering the fact that PV can be maintained for decades without significant costs after the installation (Lee, 2011). To accurately understand the effects of PV in the future, it is necessary to perform comprehensive evaluations that consider the impacts in various areas such as response to climate changes through national greenhouse gas reduction.

3.3 Greenhouse Gas Reduction by Energy Storage System

The energy storage system (ESS) can store electricity and supply it when needed, that is, it is one of the useful media that can respond to fluctuations in power demand. In this study, the greenhouse gas emission reduction was analyzed for the case where the power stored in ESS, which was generated during hours with relatively low emission factor, was used as power supply during hours when emission factor was relatively high. The lowest hour of emission factor in a day was from 11 am to 12 pm with the emission factor of 0.000461 tCO_2-eq/kWh (Fig. 3). The highest hour of emission factor in a day was from 12 am to 1 am with the emission factor of 0.000468 tCO_2-eq/kWh (Fig. 3). The difference of greenhouse gas emissions is calculated assuming that the amount of electricity stored in ESS is the same with the capacity of ESS (Table 4).

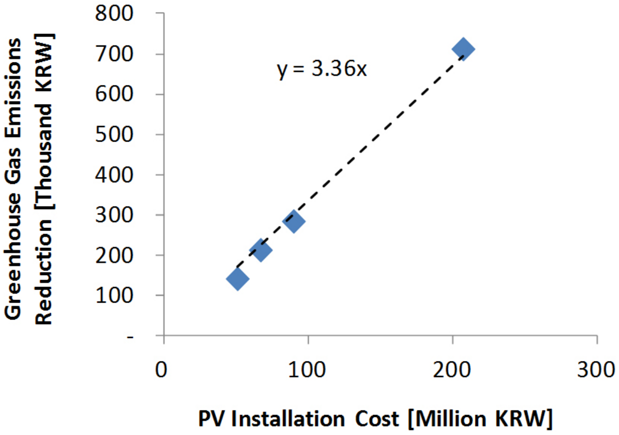

Fig. 5. Greenhouse gas emissions reduction translated in cost [Thousand KRW] vs. PV installation cost [Million KRW].

As such, the annual greenhouse gas reduction quantity per size of Korea Electric Power Corporation office building in

Table 3. Greenhouse gas emission reduction through PV

Contract demand	Over 1,000 kW	700~1,000 kW	500~700 kW	300~500 kW
(A) Annual average greenhouse gas emissions of each building due to electricity generation [Unit:tCO_2-eq]	792.5	561.0	227.5	121.6
(B) PV capacity [Unit: kW]*	100.0	40.0	30.0	20.0
(C) Greenhouse gas emission reduction through PV (B×3.5 h/d×365 d/y×0.000465) [Unit: tCO_2-eq]	59.4	23.8	17.8	11.9
(D) Reduction ratio (C/A) [Unit: %]	7.5	4.2	7.8	9.8
(E) PV installation cost [Unit: million KRW]1)*	207.0	89.8	67.0	51.0
(F) Economic effect of PV (C× 12,000 KRW) [Unit: thousand KRW]1)	713	285	214	143

1) 1,000 KRW = 0.89 USD (February 1, 2016).
* Values in Table 2 are represented again to assist readers to understand related calculations in Table 3.

Table 4. Greenhouse gas emission reduction through ESS

Contract demand	Over 1,000kW	700~1,000 kW	500~700 kW	300~500 kW
(A) Annual average greenhouse gas emissions of each building due to electricity generation [Unit: tCO$_2$-eq]	792.5	561.0	227.5	121.6
(B) ESS capacity [Unit: kWh]*	200	100	80	50
(C) Greenhouse gas emissions based on EF between 11 hr and 12 hr (B× 0.000461×1,000) [Unit: kgCO$_2$-eq]	92.20	46.10	36.88	23.05
(D) Greenhouse gas emissions based on EF between 12 hr and 13 hr (B× 0.000468×1,000) [Unit: kgCO$_2$-eq]	93.60	46.80	37.44	23.40
(E) Daily reduction of greenhouse gas emissions through ESS (D−C) [Unit: kgCO$_2$-eq]]	1.40	0.70	0.56	0.35
(F) Annual reduction of greenhouse gas emissions through ESS (E× 365/1,000) [Unit: tCO$_2$-eq]	0.51	0.26	0.20	0.13
(G) Reduction ratio (F/A) [Unit: %]	0.064	0.046	0.090	0.105
(H) ESS installation cost [Unit: million KRW]1)*	120.0	60.0	48.0	30.0
(I) Economic effect of ESS (F× 12,000 KRW) [Unit: thousand KRW]1)	6.13	3.07	2.45	1.53

1) 1,000 KRW = 0.89 USD (February 1, 2016).

* Values in Table 2 are represented again to assist readers to understand related calculations in Table 4.

2014 was 0.51 tCO$_2$-eq (over 1,000 kW), 0.26 tCO$_2$-eq (700~1,000 kW), 0.2 tCO$_2$-eq (500~700 kW), and 0.13 tCO$_2$-eq (300~500 kW), respectively. This corresponds to 0.064% (over 1,000 kW), 0.046% (700~1,000 kW), 0.090% (500~700 kW), and 0.105% (300~500 kW) of greenhouse gas emission quantity from power generation per office building (Fig. 6).

The environmental aspect of ESS analyzed through such method was converted to economy. For the conversion method, the same method used in economic analysis of PV was used, which was the application of 12,000 KRW per 1 tCO$_2$-eq. The

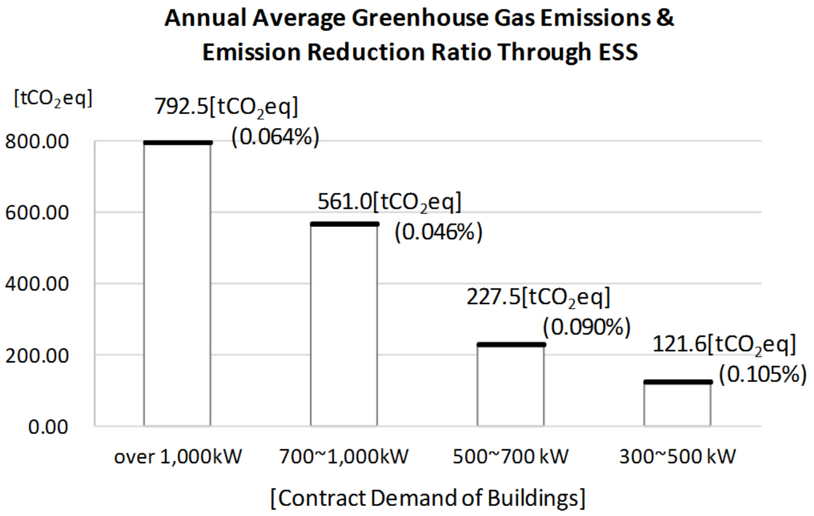

Fig. 6. Annual average greenhouse gas emissions of each building [tCO$_2$-eq] and greenhouse gas emission reduction ratio [%] due to ESS installation (illustrated inside the parenthesis on the figure).

converted economic figure was compared with ESS installation cost. As a result, greenhouse gas reduction effect per 1 million KRW ESS installation cost was found to be approximately 0.052 thousand KRW (Fig. 7). In this study, ESS efficiency was assumed to be 100%, and if the case where ESS efficiency is not 100% is considered, environmental benefit from ESS using the difference in hourly emission factor was found to be almost non-existent.

4. GREENHOUSE GAS REDUCTION BY PHOTOVOLTAIC POWER SYSTEM IN RESIDENTIAL AREAS

Up until this point, environmental aspects of photovoltaic power system (PV) installed in Korea Electric Power Corporation office buildings as a pilot project was analyzed. In this section, the environmental aspect on the extended application of PV in residential areas was estimated.

4.1 Greenhouse Gas Emission Status from Power Use in Residential Areas

The total amount of greenhouse gas emissions in Korea by 2016 was estimated at 722.0 million tCO_2-eq. From this figure, the greenhouse gas emissions from power use in residential areas is estimated at 35.5 million tCO_2-eq, which is about 5% of total greenhouse gas emissions (Fig. 8). Therefore, reduction of power usage in residential areas has a significant impact in achieving the goal of national greenhouse gas emission reduction.

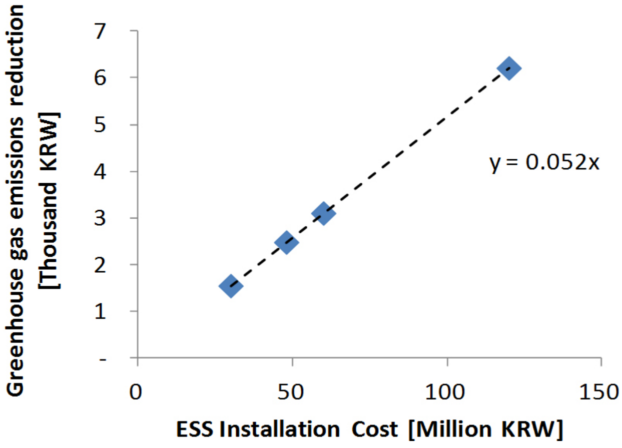

Fig. 7. Greenhouse gas emissions reduction translated in cost [KRW] vs. ESS installation cost [Million KRW].

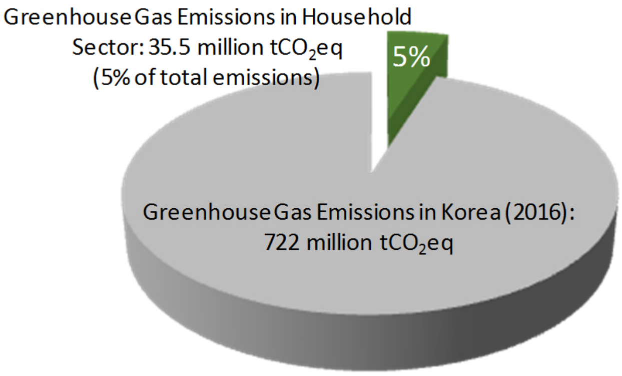

Fig. 8. Greenhouse gas emissions expected in 2016.

The total greenhouse gas emissions in 2016 was estimated by applying the average annual increase rate of 2.03% to the 2013 emission quantity of 679.8 million tCO_2-eq (ME, 2015). The greenhouse gas emission quantity from power usage in residential areas in 2016 was estimated based on the total number of housing in 2016. The total number of housing in 2016 was estimated to be 18,150,095 by using the number of housing in 2010 and the predicted number of housing in 2035 (KOSIS, 2016). Here, when the power consumption per housing area and distribution of number of housing are applied, the power consumption in residential areas in 2016 was found to be 76,344 GWh (Fig. 9 and Table 5) (KOSIS, 2016; Statistics-Korea, 2012). When this figure applied with the emission

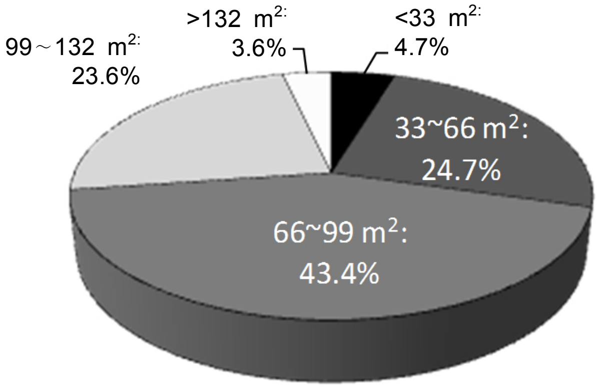

Fig. 9. Distribution of house lot area in Korea (KOSIS, 2016).

Table 5. Annual electricity usage of households in 2016

Lot area (m^2)	Less than 33	33~66	66~99	99~132	Over 132	Total
Number of houses [1]	853,054	4,483,073	7,877,141	4,283,422	653,403	18,150,095
Annual average electricity usage of each house (kWh) [2]	2,947	3,247	4,031	5,213	7,945	NA
Annual electric usage (GWh) [3]	2,514	14,557	31,753	22,329	5,191	76,344

[1] [Total Number of houses (18,150,095)] × [Distribution of lot area in Fig. 9].

[2] Statistics-Korea, 2012.

[3] [Number of houses][2] × [Annual average electricity usage][3].

factor of 0.000465 tCO_2-eq/kWh that was calculated based on electric power production ratio per annual average generating unit in 2014, the greenhouse gas emission quantity from power usage in residential areas in 2016 was 35.5 million tCO_2-eq.

Due to differences in electric power production ratio per yearly generating unit, the emission factor also shows difference depending on the year. Therefore, in order to accurately estimate greenhouse gas emissions, it is advisable to apply each yearly emission factor. However, because the yearly emission factors of 2014 and 2016 do not show a large difference in Korea and because they don't have a significant influence in this study, the emission factor of 2014 was used to estimate the greenhouse gas emission quantity in 2016.

4.2 Greenhouse Gas Reduction by Supply of Photovoltaic Power System

In this study, the environmental aspect of PV being supplied to all housing in 2016 was analyzed. By referencing the PV capacity supported by mini photovoltaic power generator project in Seoul City, the PV capacity in the residential areas were assumed to be 200W and 500W in this study (City-of-Seoul, 2016). The mini photovoltaic power generator project in Seoul City is a project that provides aid on partial expense of PV installation by Seoul City, and the PV capacity targeted for aid is diverse from 200 W to 500 W. Although there are housings that have already installed PV in the past, the environment aspect in this study was analyzed on the assumption that 200 W or 500 W PVs were equally supplied to all housings, regardless of existing installation.

Under the assumption that PV's average generating time is 3.5 hours per day, the annual power production quantity of PV per housing is 255.5 kWh/year and 638.8 kWh/year for PV capacities of 200 W and 500 W, respectively. Here, with the application of estimated number of housing in 2016, which is 18,150,095, the power production quantity from PV per PV capacity is 4,637 GWh/year (PV capacity: 200W) and 1,1593 GWh/year (PV capacity: 500W). Therefore, through the installation of 200W and 500W PVs, the greenhouse gas emission quantity can be reduced by 2.2 million tCO_2-eq and 5.4 million tCO_2-eq, respectively. These figures correspond to approximately 6% and 15% of 35.5 million tCO_2-eq of greenhouse gas emission quantity from residential areas in 2016, respectively.

4.3 Reduction of Consumer Electricity Cost by Supply of Photovoltaic Power System

Electricity cost reduction effect from PV was also analyzed in this study. Electricity cost was calculated by using monthly average power usage per housing area and electricity bill provided by the Korea Electric Power Corporation (Table 6) (KEPCO, 2016). Depending on the housing area, the monthly electricity cost reduction by installation of 200 W PV was found to be approximately 3,900 KRW (under 66 m^2), 5,000 KRW (66~99 m^2), 8,900 (99~132 m^2), and 14,000 (over 132 m^2) (Table 7). And the monthly electricity cost reduction by installation of 200 WPV per housing area was found to be approximately 10,000 KRW (under 66 m^2), 15,500 KRW (66~99 m^2), 23,000 (99~132 m^2), and 37,800 (over 132 m^2) (Table 7).

The reason behind the difference in electricity cost reduction according to housing areas despite the installation of the same capacity PV is because progressive stage system that provides savings depending on the electricity usage is applied. Therefore, homes that use large amount of electricity can have higher

Table 6. Electricity rate for residential service in Korea (KEPCO, 2016)

Monthly electric usage (kWh)	Demand charge (KRW/house)	Energy charge (KRW/kWh)
1~100	410	60.7
101~200	910	125.9
201~300	1,600	187.9
301~400	3,850	280.6
401~500	7,300	417.7
501~	12,940	709.5

electricity cost reduction even with the same capacity PV.

Annual average electricity cost reduction for PV with the capacity of 200 W was 47,00~179,000 KRW depending on the housing area (Table 7). When the PV capacity is 500W, the savings are approximately 120,000~451,000 KRW depending on the housing area (Table 7). These results show the electricity cost reduction effect that can be gained from installing PV by consumers, and at the same time, the results propose a direction for policies that can vitalize PV installation. For example, it provides information on how much reduction of PV installation cost would be persuasive for consumers if photovoltaic power system support project were to be promoted.

5. CONCLUSIONS

This study analyzed the environmental aspect of smart grid station construction project that is being promoted by the Korea Electric Power Corporation. Among the components of smart grid stations, photovoltaic power system (PV) and energy storage system's (ESS) environmental aspect were analyzed in particular.

The Korea Electric Power Corporation has been implementing smart grid station construction project on its office buildings through a phased pilot project since 2013. Through this study, it was found that 4.2~9.8% of emission quantity from power production can be reduced through the PVs installed in office buildings. In order to confirm the effect in comparison to PV installation cost, greenhouse gas emission reduction was converted by applying the emission trading price of 12,000 KRW/1 tCO_2-eq. From the result of the analysis, it was found the economy from the reduction of greenhouse gases in comparis on to 1 million KRW installation costin the installation year was 3.36 thousand KRW. To accurately understand the effects of PV in the future, it is necessary to perform comprehensive evaluation that considers impact in various areas such

Table 7. Electricity cost before and after installing PV in households in 2016

Lot area (m^2)		Less than 33	33~66	66~99	99~132	Over 132
Monthly electricity usage [kWh]	PV: Not installed[1]	246	271	335	434	662
	PV capacity: 200 W[1]	225	250	315	413	641
	PV capacity: 500 W[1]	193	218	283	381	609
Monthly electricity cost [KRW][3]	PV: Not installed	28,903	33,601	51,402	87,012	235,159
	PV capacity: 200 W	24,958	29,655	45,509	78,204	220,260
	PV capacity: 500 W	18,689	23,642	35,856	64,029	197,556
Reduction in monthly electric cost [KRW]	PV capacity: 200 W	3,945	3,946	5,893	8,808	14,899
	PV capacity: 500 W	10,214	9,959	15,546	22,983	37,603
Reduction in annual electric cost [KRW]	PV capacity: 200 W	47,340	47,352	70,716	105,696	178,788
	PV capacity: 500 W	122,568	119,508	186,552	275,796	451,236

[1] Statistics-Korea, 2012.

[2] [Electricity usage][1] minus [Electricity production by PV].

[3] Based on [Electricity usage][1] and [Electricity rate (Table 6)].

as response to climate changes through national greenhouse gas reduction in addition to economic effect from greenhouse gas reduction.

The differences in fuel usage ratio during hourly power production also led to differences in hourly emission factor. In this study, the reduction of greenhouse gas emissions that can be obtained by using the power produced during hours with low emission factor during the hours of high emission factor was estimated. The result showed that the reduction of greenhouse gas emission through ESS was insignificant due to small difference in annual average emission factor per hour. However, emission factor varies daily as well as hourly. Therefore, if a similar study is conducted by using emission factors from individual times in the future, not by using annual average values per hour, the accuracy of analysis results could be improved.

The environment factor of extending the PV installed as a part of smart grid station construction to residential areas was also analyzed. If 200~500W PVs are adapted to individual housing based on 2016, it was found that annual greenhouse gas emissions of 2.2~5.4 million tCO_2-eq could be reduced. This figure corresponds to 6~15% of greenhouse gas emissions from power production in residential areas. In addition, annual consumer electricity cost reduction was found to be 47,000~179,000 KRW from 200 WPV installation and 123,000~451,000 KRW from 500 WPV installation. Such analysis results can providein formation on what level of support for PV installation expenses would be persuasive for consumers so that current and future PV supply projects can be vitalized.

One of the limitations of this study includes assuming that the greenhouse gas emission by PV was set as zero. Because energy is used during the process of constructing PV such as system component manufacturing, transportation, installation, along with PV modules, it is unlikely that there is zero emission of greenhouse gases. As such, in order to accurately identify the impact of PV on the environment, the environmental aspect assessment should include all the processes such as PV system manufacturing, transportation, use, and disposal, including the electricity generation by using PV.

Concerning the analysis of environmental aspects of all processes of product manufacturing, transportation, use, and disposal, the representative methodology would be Life Cycle Assessment (LCA). According to a former study that analyzed environmental aspects of photovoltaic power generation from LCA perspective, the carbon dioxide emission from photovoltaic power generation was found to be 17~39 gCO_2-eq/kWh (Fthenakis and Kim, 2007; Jungbluth, *et al.*, 2005). This figure is only 3.7~8.5% of 465 gCO_2-eq/kWh, which is the greenhouse gas emission from power generation in Korea mentioned earlier. However, such previous study results show that photovoltaic power generation also produces greenhouse gases even if it is only in small quantities. If the relevant data necessary for LCA analysis such as energy usage per manufacturing, transportation, usage, and disposal phases are gathered and added to LCA on photovoltaic power system, the accuracy of environmental analysis result of smart grid station construction could be improved.

Another limitation of this study can said to be the use of carbon dioxide emission trading price at 12,000 KRW/1 tCO_2-eq in order to convert greenhouse gas reduction of smart grid adaptation into cost reduction. The emission trading system is a system for selling and purchasing excess and deficiency, where a company that has emitted be low the given greenhouse gas emission quota can sell the excess to another company, and contrastingly, a company that has exceeded the given greenhouse gas emission quota can purchase from another company.

Companies that have lower greenhouse gas reduction cost compared to the price in the emission trading market would continue greenhouse gas reduction activities, but companies that have higher cost of reducing the limit compared to carbon dioxide emission trading price would purchase emission quota. Therefore, when emission trading system is active and emission price is autonomously determined by the market, the emission price would be set near the average cost of greenhouse gas reduction cost across all industries. However, because the trading amount is still limited and trading price has not been autonomously determined, emission trading price cannot accurately reflect the greenhouse gas reduction costs.

In particular, the maximum potential greenhouse gas reduction in the industry is currently very limited and the greenhouse gas reduction cost is also known to be very high compared to emission trading price. For example, the marginal cost of greenhouse gas reduction in the steel industry, that is, the cost of reducing 1 ton of greenhouse gas was found to be approximately 120,000 KRW according to the result of analysis based on the largest steel company in Korea (KEMCO, 2012). In addition, the marginal cost of reduction in the chemical fiber industry was found to be around 130,000~180,000 and the marginal cost of reduction in the power generation industry was around 222,000 KRW based on 2010 (KEMCO, 2012). As such, there is a possibility that the greenhouse gas reduction from smart grid station construction could have been underestimated in this study due to the conversion of greenhouse gas reduction that used the emission trading price of 12,000 KRW/1 tCO_2eq. If accurate analysis results on the cost required to reduce greenhouse gases are used in future studies, the accuracy of environmental analysis on smart grid station construction would be improved.

ACKNOWLEDGEMENT

This research was supported by the research fund provided by Korea Electric Power Corporation.

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